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BACKWARD-MASKING: THE EFFECT OF THE DURATION OF THE SECOND STIMULUS ON RECOGNITION OF THE FIRST STIMULUS

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Abstract—Objective: We recorded event-related magnetic fields following a target stimulus followed by a masking stimulus to investigate the visual backward masking effect using a helmet-type magnetoencephalography system in humans.

Methods: In the target stimulus with masking stimulus conditions, duration of the target stimulus was constant at 16 ms, and duration of the masking stimulus was altered (16, 48 and 144 ms). The target stimulus was masked by the 144-ms masking stimulus, but not by the 16-ms masking stimulus, and was obscured by the 48-ms masking stimulus. For control conditions (Single-condition), event-related magnetic fields were recorded following the sole presentation of the masking stimulus for 32, 64 or 160 ms.

Results: One major response was obtained at 180 ms after the onset of the stimulation in each condition. The equivalent current dipole of one major response was estimated to lie in the occipital lobe, but there was a relatively large inter-individual difference. There was no significant difference in latency between the target stimulus with masking stimulus conditions and Single-conditions. In the target stimulus with masking stimulus conditions with the 48- and 144-ms masking stimulus, the root mean square value did not differ from that in the respective Single-condition, while the root mean square value for the target stimulus with masking stimulus conditions with the 16-ms masking stimulus was significantly smaller than that in the Single-condition with the 32-ms masking stimulus, but not different from that in the Single-condition with the 16-ms masking stimulus.

Conclusions: The peak latency of one major response depended on the onset of the first stimulus for both the target stimulus with masking stimulus conditions and Single-condition, but the root mean square value depended on the duration of the masking stimulus. We concluded that the temporal information for the target stimulus was preserved during the masking effect, while the figural information was interrupted by the masking stimulus. Our results suggested that temporal factors for the stimulus were processed differently from those responsible for the object's recognition during backward masking.

Key words: cognition, ERF, MEG, stimulus duration, visual process.

Consciously recognized objects are not always identical to real objects, but our brain processes them differently without an awareness of what they really are. We are actually surrounded by various stimuli in our daily life, and some components such as size, color and luminance, may not be consciously perceived. Therefore, it has been of interest to investigate the difference of mechanisms between conscious and unconscious perception (Lamme et al., 1998; Lamme and Roelfsema, 2000; Bar et al., 2001; Kellman, 2003; Lamme, 2003). To clarify the issue of unconscious perception, a stimulus technique, backward masking, has been used in experimental designs. Backward masking is the phenomenon whereby the conscious perception of a first stimulus is interfered with by a second stimulus. In such a situation, the first stimulus cannot be perceived, although the stimulus partially activates the visual system (Rolls et al., 1999). The backward masking effect has been found in the auditory (Greenwald, 2003; Petkov et al., 2003), visual (Kovacs et al., 1995; Rolls et al., 1999; Grill-Spector et al., 2000; Kondo and Komatsu, 2000; He and MacLeod, 2001; Breitmeyer et al., 2004) and somatosensory (MacIntyre and McComas, 1996; Imanaka et al., 2002) systems, and there have been many reports on the underlying mechanisms, particularly the spatio-temporal characteristics of the masking effect (Rolls et al., 1999; Breitmeyer and Ogmen, 2000; Francis, 2000; Kondo and Komatsu, 2000; Vidnyanszky et al., 2001; Lamme et al., 2002; Enns, 2004). In studies using functional magnetic resonance imaging (fMRI) and positron emission tomography (PET), the relationship between the temporal connection for the initial and subsequent stimulus during backward masking was investigated (Desmurget et al., 2000; Bar et al., 2001; Lerner et al., 2004). However, since backward masking occurs within several hundred milliseconds after the stimulation, recording equipment with a high temporal resolution is needed to study the mechanism. Magnetoencephalography (MEG) has a higher temporal resolution than fMRI and PET, and is one of the most appropriate methods of studying event-related brain responses.

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Abbreviations: ANOVA, analysis of variance; ECD, equivalent current dipole; ERF, event-related magnetic fields; fMRI, functional magnetic resonance imaging; GOF, goodness of fit; HPI, head position indicator; ISI, inter-stimulus interval; MASK, masking stimulus; MEG, magnetoencephalography; MRI, magnetic resonance imaging/images; PET, positron emission tomography; RMS, root mean square; S.D., standard deviation; SOA, stimulus onset asynchrony; TARGET, target stimulus; TM-condition, TARGET-MASK condition; 1M, major component of evoked magnetic fields.

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In the present study, employing an MEG system, we compared the brain responses to a stimulus with and without backward masking effects. Previous psychophysical studies of backward masking mainly focused on the effect of stimulus onset asynchrony (SOA), the time difference between the onset of the first (target) and the second (mask) stimulus (Rolls et al., 1994, 1999; Breitmeyer and Ogmen, 2000; Francis, 2000; Bar et al., 2001; Breitmeyer et al., 2004; Deary et al., 2004). However, since evoked brain responses are affected by both target and masking stimuli, stimulus condition with various SOA is considered to cause complex responses. To avoid such complexity, we focused on clarifying the effect of the duration of the masking stimulus (MASK) on the conscious perception of the stimulus while keeping the SOA fixed in the present study. The effect of the duration of masking was studied psychologically by Di Lollo et al. (2004), but we investigated the mechanisms using a neurophysiological technique, MEG.

EXPERIMENTAL PROCEDURES

Subjects

Thirteen healthy volunteers (10 males and three females, 35.6±8.9, mean±standard deviation (S.D.), years) participated in the study. The subjects had no history of neurological disease, and their visual acuity was corrected within the normal range by contact lenses, if needed. The objective and the procedure of the study were explained to the subjects, and their informed consent to participate in the experiment, which was first approved by the Ethics Committee of the National Institute for Physiological Sciences, was obtained prior to the study.

Visual stimuli

All stimuli were projected on a screen 230 cm in front of the subject by a liquid crystal projector system (Mirage 2000, Christie Digital Systems Inc., Ontario, Canada). Since backward masking is the phenomenon whereby the first stimulus is influenced by the second stimulus, we describe the first and second stimulus as the target stimulus (TARGET) and MASK, respectively in the present study. We created TARGET and MASK based on two criteria used in previous reports (Treisman and Gelade, 1980; Kondo and Komatsu, 2000; Nothdurft, 2000; He and MacLeod, 2001; Takeuchi et al., 2004; Di Lollo et al., 2004). Those criteria are; (1) all subjects can recognize both stimuli, when each stimulus is solely presented, and (2) the luminance of each stimulus is as low as possible to reduce the visibility of the TARGET when the MASK duration was long, but each stimulus can be still discriminated by the subjects. Consequently, we used two stimuli as follows. The first stimulus (TARGET) was a figure of a cross (0.38×0.38° visual angle), while the second stimulus (MASK) was a circle (0.6×0.6°) on the background. Both were placed 1.1° to the left of the fixation point at the center of the screen (Fig. 1a). Thus, the TARGET and

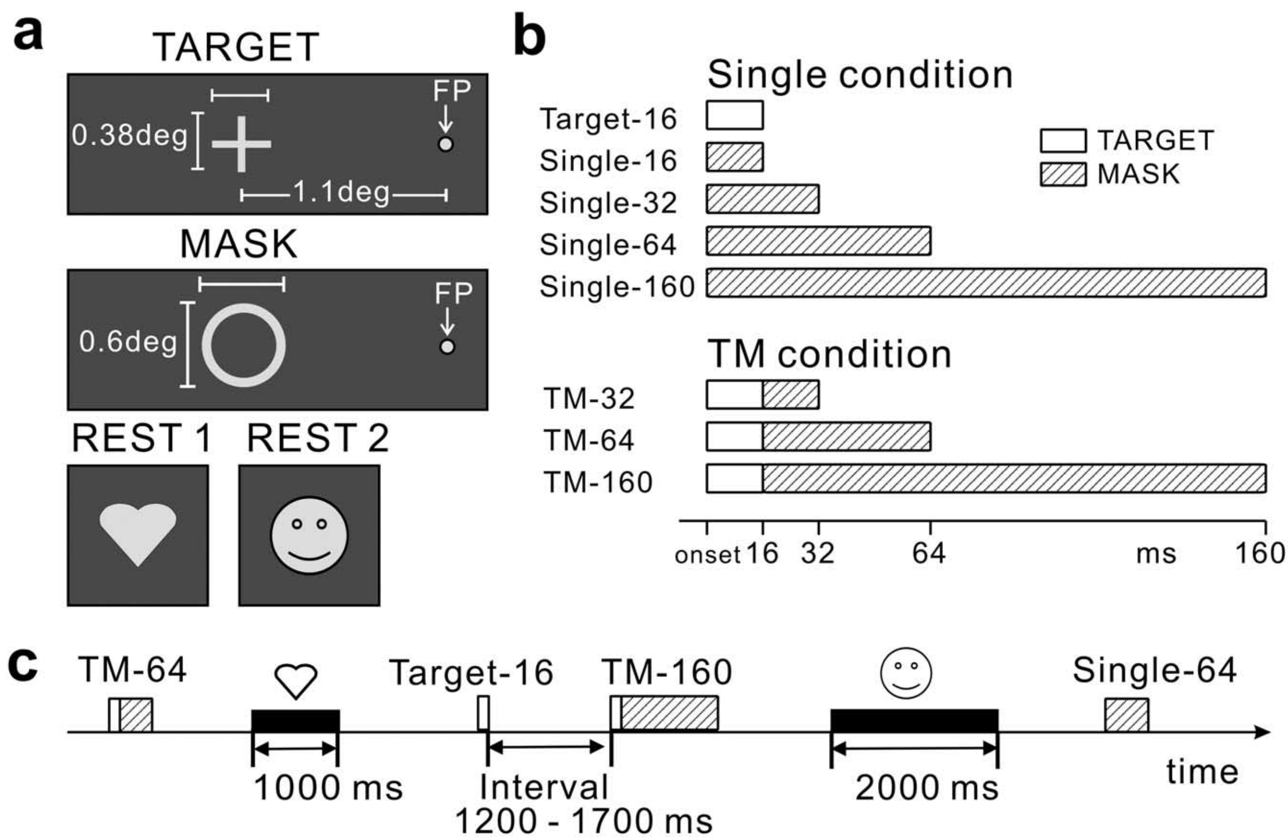

Fig. 1. Experimental design. (a) The cross used for the TARGET (first stimulus) and circle used for the MASK (second stimulus). Figure of a heart (REST 1) and a face (REST 2) were presented during the rest period, and the former was used for counting the stimulus to keep the subject's attention on the screen. (b) Stimuli for the Single-condition and TARGET-MASK-condition (TM-condition). Each TARGET and MASK was presented alone in the Single-condition, while in the TM-condition, the TARGET was presented for 16 ms followed by the MASK for various periods. (c) Time sequence of stimulation: Each stimulation in the Single- and TM-condition was presented randomly in one recording sequence.